TITLE: InAs Self-Organized Quantum Dots Grown by MOVPE in In0.53Ga0.7As Matrix

Ioffe Institute
6th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 22–26, 1998.

InAs self-organized quantum dots grown by MOVPE in $In_{0.53}Ga_{0.47}As$ matrix

O. V. Kovalenkov, I. S. Tarasov, D. A. Vinokurov and V. A. Kapitonov
Ioffe Physico-Technical Institute, St. Petersburg 194021, Russia
E-mail: oleg@movpe.ioffe.rssi.ru

Abstract. The results of the self-assembling Stranski-Krastanow growth of InAs quantum dots embedded in $In_{0.53}Ga_{0.47}As$ by low pressure MOVPE are presented. The structures were investigated by room and liquid nitrogen photoluminescence method. The highest obtained emission wavelength of 2.1 μm at room temperature is the longest value for InAs quantum dots reported in literature until now.

Introduction

The self-organized fabrication of the low dimensional semiconductor structures with coherent nanoscale islands (so called quantum dots) grown in Stranski-Krastanow growth mode has been a subject of intensive investigation in the last years. These structures have an unique electrophysical properties because of tree-dimensional confinement of carriers in the island volume.

One of the most extensively studied material system is the self-organized InAs islands on GaAs substrates. Semiconductor lasers based on InAs and InGaAs active region with low threshold current density (100 A/cm^2) and high characteristic temperature at room temperature ($T_0 = 385$ K) have been demonstrated [1, 2, 3].

However, there are a very few reports on the growth of InAs islands on InP substrates [4, 5, 6]. This material system might be a promising candidate for fabrication of low threshold QD-based lasers operating at the wavelength range of 1.5–2 μm which is important for high resolution molecular spectroscopy and atmosphere pollution monitoring.

1 Experimental

In this paper we present the results of self-assembling Stranski-Krastanow growth of InAs islands on InP by the low pressure metal organic vapour phase epitaxy (MOVPE). The processes were carried out in rectangular horizontal reactor operating at pressure of 100 mBar with radio frequency heating of graphite susceptor. The thrimethylgallium (TMGa), thrimethylindium (TMIn), arsine and phosphine diluted in hydrogen were used as sources of elements. The growth temperature was varied in the range of 500–600°C. Exactly oriented InP (100) substrates were used. Before the growth the substrates were degreased with the boiling organic solvents and then etched with $K_2Cr_2O_7$:HBr.

The investigated structures consist of 0.3 μm bottom cladding $In_{0.53}Ga_{0.47}As$ (hereafter referred as InGaAs) layer followed by the InAs quantum dots (QD) and 0.04 μm of

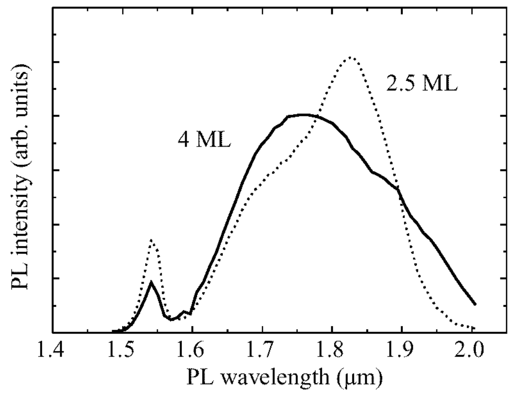

Fig 1. 77 K PL spectra of InAs/InGaAs QDs for two InAs deposition thicknesses.

upper InGaAs. The growth rate for barriers and QD were 8 Å/s and 2 Å/s, respectively. The nominal InAs deposition was varied between 1.5 and 4 monolayers (ML).

Inspite of the low energy gap difference between our ternary InGaAs barriers matched to InP substrate and QD we choose this material combination to avoid the parasitic V group exchange reactions of P-As on interfaces for InP/InAs system [4, 5, 6, 7] leading to formation of intermediate ternary InAsP layer [7]. The driving force behind forming a such layer comes from low binding energy of P and As. These reactions make this system sufficiently complicated and in dependence on growth conditions the various photoluminescence (PL) peak positions in the range of 0.9–1.8 μm have been obtained [4, 5, 6].

Moreover, the unintentional As/P exchange during InAs QDs growth on InP can lead to formation of ternary InAsP dots which should have a lower PL wavelength as compare to InAs ones. This can complicate of composition control in dots and, consequently, the emission wavelength in a such material combination.

2 Results and discussion

The room (300 K) as well as liquid nitrogen (77 K) PL measurements were performed for investigation of grown samples. As the excitation source we used the 514 nm line of argon ion laser. The excitation density was 50 W/cm^2.

The PL spectra of structures grown at 600°C with nominally 2.5 MLs and 4 MLs of deposited InAs are shown on Fig. 1. The growth interruption (GI) at interfaces were 5s before and after QD deposition in InAs and InP ambient, respectively. GI was introduced due to continuous growth can suppress the island formation [8, 9]. The PL peak at 1.5 μm arise from the ternary barrier. The broad high intense peaks may be attributed to emission from QDs. The splitting of peaks may testify the presence of two different size of islands.

Fig. 2 shows the 77 K PL spectra for samples containing of 4 MLs InAs nominally, grown at temperature of 600°C. Curves 1 and 2 with the same growth sequence as in the Fig. 1 show that the PL peak position does not depend on V/III ratio in gas phase at least in the range of 40 (curve 1) to 320 (curve 2). Curve 3 in Fig. 2 shows the substantial narrowing of PL peak due to introducing of long time (120 s) GI in AsH_3

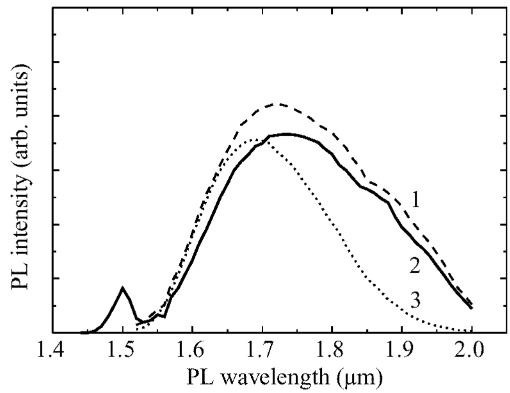

Fig 2. 77 K PL spectra of InAs/InGaAs QDs different growth conditions.

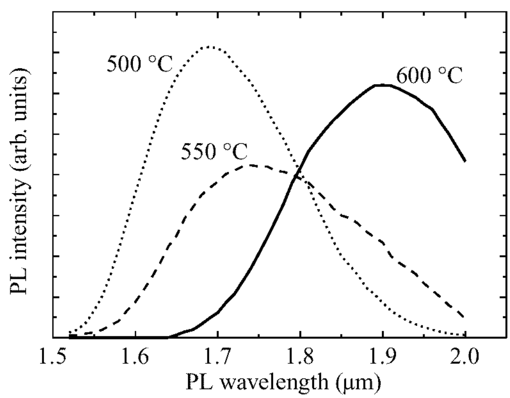

Fig 3. 77 K PL spectra of InAs/InGaAs QDs for different growth temperatures.

flow before QD growth. This phenomenon may be connected with reorganization of lower barrier surface what permitted to grow the more uniform in size QDs. The narrowing of PL peaks after thermal annealing of completely grown structures have been reported in literature [10].

The effect of the growth temperature on the PL spectra transformation is presented in Fig. 3 which shows the 77 K spectra of samples with 4 MLs of InAs islands nominally. After the bottom InGaAs layer has been grown at the temperature of 600°C the growth was interrupted in AsH_3 ambient during 120 s to decrease the temperature for QD deposition. The upper barrier was grown at the same temperature as QD region after 5 s of GI in PH_3 flow to QD formation. As clearly seen from Fig. 3 the lower the QD formation temperature the higher PL peak position. For lower investigated temperature of 500°C the peak is centered at 1.91 μm which corresponds 2.1 μm (0.6 eV) at room temperature. This value is the highest emission wavelength for InAs dots grown on InP substrate.

3 Conclusion

In summary, the self-organized InAs quantum dots embedded in InGaAs have been grown by the low pressure MOVPE. Photoluminescense measurements performed at room and liquid nitrogen temperature showed that InAs QDs grown in InGaAs matrix matched to InP substrate at appropriate growth conditions are a promising candidate for optoelectronic devices operated in spectral range of 1.9–2.1 μm. This value is the longest emission wavelength for InAs dots reported so far.

This work was partially supported by the program "Physics of solid state nanostructures" (Grant No. 96-2005).

References

[1] Zh. I. Alferov, N. Yu. Gordeev, S. V. Zaitsev, et al., *Semiconductors* **30** 197 (1996).
[2] M. V. Maximov, N. Yu. Gordeev, S. V. Zaitsev, et al., *Semiconductors* **31** 124 (1997).
[3] M. V. Maximov, I. V. Kochnev, Yu. M. Shernyakov, et al., *Int. Phys. Conf. Ser.* N 155, ch. 7, p. 557 (1996).
[4] S. Fafard, Z. Wasilewski, J. McCaffrey, et al., *Appl. Phys. Lett.* **68** 991 (1996).
[5] A. Ponchet, A. Le Corre, H. L. Haridon, et al., *Appl. Phys. Lett.* **67** 1850 (1995).
[6] N. Carlsson, L. Samuelson, and W. Seifert, *EW MOVPE VII*, Berlin, G12 (1997).
[7] M. Mesrine, J. Massies, E. Vanelle, et al., *Appl. Phys. Lett.* **71** 3552 (1997).
[8] O. V. Kovalenkov, D. A. Vinokurov, D. A. Livshits et al. Intern. Symp. "Nanostructures: Physics and Technology", St. Petersburg, Russia, p. 141 (1996).
[9] O. V. Kovalenkov, D. A. Vinokurov, D. A. Livshits, et al., *Int. Phys. Conf. Ser.* N 155, ch. 3, p. 271 (1996).
[10] A. E. Zhukov, A. Yu. Egorov, A. P. Kovsh, et al., Int. Symp. "Nanostructures: Physics and Technology", St. Petersburg, Russia, p. 132 (1996).